SIMULATION FIDELITY: A RATIONAL PROCESS FOR ITS IDENTIFICATION AND IMPLEMENTATION

Robert C. Bruce, Ed.D.
AAI Corporation
Instructional Systems Development
York Road and Industry Lane
Cockeysville, Maryland 21030

ABSTRACT

The degree of fidelity required in simulators to effectively transfer newly acquired skills between the classroom and the work world remains illusive and ill-defined during the front end analysis of system design. Frequently, fidelity specifications are inconsistent between the ultimate users of the system, the acquisition agency, and the contractor charged with the design and production of the final training system. Such a situation is not in the best interest of the student and is likely to produce a device insensitive to the directions provided by sound instructional and engineering analyses. This paper presents a technique for allowing individual training tasks to define specific degrees of simulator fidelity and then objectively tracking the task/fidelity relationship throughout the design, development, and testing phases.

INTRODUCTION

For over 25 years, AAI Corporation has been responsible for the design and production of training devices requiring various degrees of fidelity. During this period, it became apparent that terms such as 100-percent fidelity, full fidelity, etc, were an enigma. In an effort to define the issue of simulator fidelity, or more precisely, "How much fidelity is enough?", AAI developed a model that would allow the training requirements to design the ultimate training systems. In this fashion, if the simulator could totally support the tasks for which it would be held accountable, then the inherent level of fidelity was sufficient.

Defining these training requirements took the combined expertise of personnel with training and systems engineering backgrounds. Using the instructional systems development (ISD) approach, the entire process was conducted in parallel to *simultaneously identify tasks to be trained and* required levels of task fidelity. Extensive analysis was continuously performed on the collected data to further refine them to a point where valid design decisions could be made.

FRONT END ANALYSIS

To derive the fidelity requirements for each simulator, a comprehensive front end analysis (FEA) was conducted. AAI's research effort initially concentrated on the accurate definition and validation of critical tasks to be trained. These tasks were collated and refined to develop a preliminary task list for each anticipated simulation work station type. A team of training specialists and systems engineers then visited operational sites to observe job incumbents, interview subject matter experts (SME's), collect additional data, and validate the critical tasks to be taught on the training system. The product of this effort was a validated list of training tasks that would have to be supported by the ultimate training system.

After the results of the data research, collection, and validation efforts were analyzed and refined, each training task was classified to a learning category. Each learning category defined the optimum testing environment and instructional delivery media to satisfy the learning activity of each training task. The appropriate medium for each task was selected and documented in a Media Summary. These data were then resorted by subsystem for each job and aggregated to the highest level of fidelity required to support all of the tasks taught on each individual panel. These data were documented in a Panel Summary. The fidelity requirements for each of the equipment panels were combined to define the fidelity requirements for each simulation work station as determined by the associated training tasks.

FIDELITY DEFINITION

Rouse (1982) defined fidelity as "the precision with which the simulator reproduces the appearance and behavior of the real equipment." Hays (1981) proposed a similar definition as "the degree of similarity between the training simulator and the equipment being simulated in terms of its physical and functional characteristics." Massey (1986) has added additional clarification by identifying two *basic types of fidelity: physical and nonphysical.* AAI has translated the physical and nonphysical into specific requirements of physical and functional fidelity and added a third requirement of task commonality. To illustrate AAI's definition of fidelity requirements, the reader must first understand the relationship between the components of the job that the student will ultimately be required to perform at the completion of training. Each component requires its own degree of fidelity support. This relationship is shown on Figure 1 and is discussed in the following paragraphs.

As observed on Figure 1, the identifier 1.B.55.1 equates to the JOB of On-Line Maintenance Technician, the DUTY of Implementing Preventive Maintenance Procedures, the TASK of Cleaning Unibus Expansion Box, no SUBTASK, and ACTIVITY of Preparing the Unit for Cleaning; therefore, task number 1.B.55.1 will always equate to preparing the UEB for cleaning, regardless of where this activity is documented (e.g., preliminary task lists, learning hierarchy, learning objective, course outline, or tests). The Tasks Listings Report output (Figure 2) shows this information in the following manner.

The fidelity requirements for each activity are summed at the task level. When all tasks within the duty have been defined, the corresponding fidelity requirements are summed to define 100-percent fidelity for that duty category. All duty categories are ultimately defined and the total fidelity requirements are then easily gathered to drive the design of the individual simulation work stations.

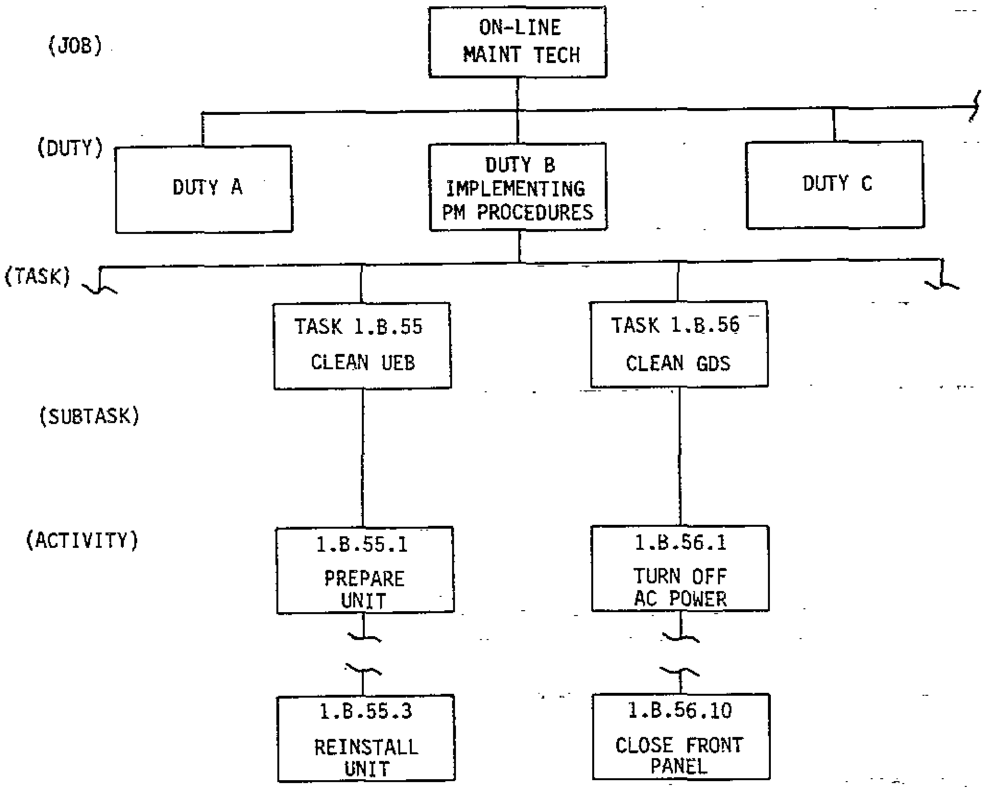

Figure 1. Relationship Among Job Components

The above example has been presented from a top-level perspective without regard to the technical specifications required of the design engineers. It does, however, serve to illustrate the method of identifying fidelity requirements at the lowest level, gathering fidelity issues as the design personnel work up the training components, and ultimately specifying the total simulation work station at the job level.

Each required training task is supported by 100-percent physical and functional fidelity required to ensure that the students gain the skills necessary to do their job in the field. This 100-percent degree of fidelity is translated by the design engineers into specific hardware and software requirements at the lowest activity level. In other words, if a student is required to manipulate a series of events by pressing buttons, changing switch settings, or entering keyboard data, the student work station will provide a simulated operational environment that presents 100 percent of the physical and functional fidelity associated with the real-world cues, responses, and feedback to provide the direct transfer of newly acquired skills into the work world. The following section provides an example of how this is implemented and the fidelity requirements verified throughout the design and development process.

FIDELITY VERIFICATION (FV) MODEL

AAI's fidelity verification approach was modeled after a method for evaluating training device effectiveness reported by the U.S. Army Research Institute for the Behavioral and Social Sciences (Tufano and Evans, 1982). The reported TRAINVICE-A (TV-A) model was modified to facilitate a predesign approach vice the original intent of evaluating a fielded training system. AAI's fidelity verification (FV) model provides an objective rating of the correspondence between the training device and the operational equipment as defined by the required training objectives. The product of all the measured variables becomes the training device fidelity index (FI) and serves to provide a quantitative comparison between the training device (as defined by the training tasks) and the operational equipment that it represents. In the FV model, the training device is evaluated by comparing the required training and operational tasks and the fidelity index is adjusted if additional (i.e., unique) features are included in the device beyond those required by the Task Listings Report. The assumption is that training additional skills may add unnecessary costs that may lead to a loss of device effectiveness.

The FV model allows values to be assigned to basic device characteristics, subdivided into the following categories.

- <u>Task Commonality</u> - Comparison between the operational requirements and the training tasks
- <u>Physical Similarity</u> - Comparison between the physical characteristics required by the training tasks and the simulation work station
- <u>Functional Similarity</u> - Comparison between the functional characteristics required by the training tasks and the simulation work station

JOB: On-Line Maintenance Technician OBSERVER: ____________

DUTY: Implementing Preventive Maintenance Procedures

TASK NUMBER	TASK DESCRIPTION	TASK FIDELITY	REFERENCE SOURCE
B.55	Clean UNIBUS expansion box.	(See Note 1.)	(See Note 2.)
B.55.1	Prepare installed unit for cleaning.		
B.55.2	Perform general cleaning.		
B.55.3	*Reinstall unit after cleaning.*		
B.56	Clean RAMTEK 9460 Graphics Display System (GDS).		
B.56.1	Turn off AC power.		
B.56.2	Open front panel.		
B.56.3	Disconnect all cables from the circuit card assemblies.		
B.56.4	Remove each circuit card.		
B.56.5	Vacuum interior.		
B.56.6	Vacuum circuit cards.		
B.56.7	Wipe down exterior with soft cloth and cleaner.		
B.56.8	Reinstall circuit cards.		
B.56.9	Reattach connectors.		
B.56.10	Close front panel.		

NOTE 1: Document the appropriate cues, required responses, acceptable proficiency levels, response times, etc, for each activity or step.

NOTE 2: Document the reference source from which the task was derived. This may be restricted to the task level and will include document title, number, and date; section identification; and page number. Abbreviations are acceptable if a legend is included.

Figure 2. Tasks Listings Report Format

Values assigned to these categories are combined to produce the fidelity index of each training device. The information required to perform an FV analysis includes:

- List of hands-on tasks/subtasks to be trained (derived from the Tasks Listings Report)
- Description of the controls and indicators used to perform the tasks/subtasks in the operational setting
- Description of the controls and indicators in the training device

Each of the categories cited above individually provide important information on the development of operational training devices. Collectively, however, they provide crucial data early in the design process, which facilitates the verification of critical fidelity concerns. For example, physical fidelity of panels can be verified by inspection during drawing preparation and again after manufacture. Functional fidelity, while identified during the front end analysis, cannot be fully verified until qualification testing but can be confirmed during system and design reviews. The application of this verification process early in the development stage serves to lower the risk and cost associated with the total training program.

Task Commonality (TC) Analysis

The task commonality (TC) analysis in the FV model determines a value for each task by rating whether or not operational tasks that require *training are covered on the training device* (1 = covered, 0 = not covered). The TC value for a duty is calculated by adding all task (T) ratings within that duty and dividing this sum by the total number of required tasks (TR_t) as determined from the approved Tasks Listings Report. During the TC analysis, subtasks are evaluated in the same manner as higher order tasks. For example, a task with three subtasks would be viewed as three separate items and could receive a maximum rating of 3 (subtask 1 = 1, subtask 2 = 1, and subtask 3 = 1) instead of a maximum rating of 1 as if it were a single task; therefore, in this model, the terms task and subtask are used interchangeably.

The TC formula is as follows:

$$TC = \frac{T_1 + T_2 + T_n}{TR_t}$$

The task rating scale is defined as follows:

1 = Training device does allow practice of the operational task element.

0 = Particular task element is not represented in the training device.

Physical Similarity (PS) Analysis

In the physical similarity (PS) analysis, the controls and indicators on a training device are evaluated in terms of their size, shape, color, etc, with respect to the operational equipment. In other words, each control and indicator required of the training device is rated against the degree of physical similarity between it and the corresponding control or indicator on the operational equipment. The rating scale used for this purpose is 0 (missing), 1 (dissimilar), 2 (similar), and 3 (identical).

In order to derive a PS index for each task, the ratings given to the physical controls and displays (PCD's) on a device are totaled. This sum is then divided by a combination of 3 times the total number of required controls and displays (RCD_t) plus the number of unique controls and displays (UCD_t). The unique controls and displays on a device are those represented on the trainer but are not associated with the individual task/subtask or activity being evaluated. Thus, the resulting index varies between 0 and 1.00, representing the physical similarity, adjusted for extra or unique features.

The PS formula is shown as follows:

$$PS = \frac{PCD_1 + PCD_2 + PCD_n}{3\ (RCD_t + UCD_t)}$$

The PCD rating scale is defined as follows:

3 = Identical. The trainee would not notice a difference between the training device control or indicator and the operational control or indicator when he or she moves from the training environment to the job situation. Include for consideration the location, appearance, feel, and any other physical characteristics.

2 = Similar. There would be a small noticeable difference for the trainee between the training device control or indicator and the operational control or indicator, but he or she would be able to perform the task. There might be a decrement in performance, but any such decrement would be small and readily overcome.

1 = Dissimilar. There would be a large, *noticeable difference*, quite apparent to the trainee, between the training device control or indicator and the operational equipment and a large decrement, given that the trainee could perform at all. Specific instruction and practice would be required on the operational equipment after practice on the training device to overcome the decrement.

0 = Missing. The control or indicator is not represented at *all in the training* device.

Functional Similarity (FS) Analysis

The functional similarity (FS) analysis compares the controls and indicators of a training device to those in the operational equipment in terms of amount of information conveyed from or to the human operator. Just as in the PS analysis, each of the required controls or indicators relevant to a particular task/subtask receives a rating from 0 *(missing) to* 3 *(identical)*.

In order to calculate the FS index for each task, the ratings given to all functional controls and displays (FCD's) on a device are summed and the total is divided by a combination of 3 times the total number of required controls and displays (RCD_t) plus the unique controls and displays (UCD_t). This results in an index ranging from 0 to 1.00.

The FS formula is shown as follows:

$$FS = \frac{FCD_1 + FCD_2 + FCD_n}{3\ (RCD_t + UCD_t)}$$

The FCD rating scale is defined as follows:

3 = Identical. The number of states in the training situation is the same as the number of states in the operational setting (as defined by the training tasks).

2 = Similar. The number of states in the training situation is at least 75 percent of the number of states in the operational setting (as defined by the training tasks).

1 = Dissimilar. The number of states in the training situation is less than 75 percent of the number of states in the operational setting (as defined by the training tasks).

0 = Missing. The control or indicator is not represented at all in the training device.

COMPUTING DEVICE FIDELITY USING THE FV MODEL

Just as the identification of fidelity requirements are at the task level, so too is the application of the FV model. Each task is analyzed and quantitatively evaluated against the operational equipment as previously discussed.

Again, using the example previously cited, the FV values for task B.55 may be seen as TC = 1.00 and *FS = 1.00 (the assumption in this example* is that each task/subtask and tactile and functional fidelity is identical to that of the operational environment).

FC values are computed in a similar manner for each task within each duty category. Consequently, values are totaled at the duty level and FV values can be extracted for task commonality and physical and functional fidelity. Just as the identification of fidelity requirements was gathered from each duty category and used to define the simulation work station requirements, the duty FV values are gathered and a device fidelity index (FI) is derived.

The FV Fidelity Worksheet is shown on Figure 3 with task B.55 entered to illustrate the application of the FV model. Worksheets are normally separated by duty category and FV values assigned after all the tasks within the duty category have been analyzed (it is a simple matter to isolate individual tasks within the duty category and compute the FV values separately). The computational (lower) portion of the worksheet would appear only on the last page of each duty category being evaluated. This organization easily facilitates the computation of the FV index for each duty category.

On Figure 3, the total value of the tasks (tasks and subtasks) is assumed to be 65; there are 65 required tasks on the device; the physical similarity total value is 144 with 50 required controls/displays and 15 unique controls/displays; and the functional similarity total value is 162 with 65 required control/display actions and no unique control/display actions. The values for this duty, within the previously cited parameters, are TC = 1.00, PS = 0.74, and FS = 0.83.

The analyses just presented are used to calculate an overall fidelity index for each duty. The total values for TC, PS, and FS are summed and divided by 3. This value represents the overall degree of correspondence between the training device and the operational equipment, as defined by the training objectives, for the duty being evaluated. The fidelity index (FI) value for each duty will range from 0 to 1.00. This value is based on the premise that the higher the level of fidelity (1.00 or 100 percent) the more effective the training device; as the level of fidelity decreases, there will be a corresponding decrease in its ability to teach course objectives. In the prior example, the TC value of 1.00, PS value of 0.74, and FS value of 0.83 are combined to yield a total fidelity index (FI) of 0.86 (1.00 + 0.74 + 0.83 divided by 3) for duty B.

Therefore, for duty B of the hypothetical simulator used in explaining the fidelity verification model, the training device is 86 percent (FI = 0.86) identical to the actual operational equipment (tasks and tactile and functional fidelity) as defined by the lowest order learning activities. In this example, the 100-percent fidelity requirement was not met (i.e., FI = 0.86); consequently further analysis is required to identify the deficient task(s) and to initiate corrective action. The FV model supports this analysis and allows individual components (tasks/activities) to be isolated for further investigation and modification. At the job (simulation work station) level, the FV values for each duty can be gathered and averaged to provide a figure of device quality. It should be remembered, however, that the fidelity issues are identified and resolved at the lowest levels (duty, task, and activity).

IMPLEMENTING THE FV MODEL

The FV model, in consonance with the emerging Task Listings Report, will initially be applied to all early system design discussions. As the front end analysis reaches maturity, the individual fidelity issues will redefine system parameters and the FV model will provide both contractor and Government personnel with a vehicle for verifying fidelity accuracy.

JOB: RPV INTERNAL PILOT   OBSERVER: BILLY BOB "BUBBA" NESMITH

DUTY: CONDUCTING PREOP/PRELAUNCH ACTIVITY

TASK/SUBTASK	TC 0-1	PS 0-3	FS 0-3
B.5 CONDUCT RPV AUTO TEST	1		
B.5.1 CONDUCT ELEC SYSTEM TEST			
FUNCTIONAL KB		3	3
FUNCTIONAL CRT		3	3
SIM TEST SEL MENU		3	3
SIM ELEC PS TEST			3

TC = TASK COMMONALITY
PS = PHYSICAL SIMILARITY
FS = FUNCTIONAL SIMILARITY
T_t = TOTAL TC VALUE
TR_t = TOTAL REQUIRED TASKS
PCD_t = TOTAL PS VALUE
RCD_t = TOTAL NUMBER OF REQUIRED CONTROLS DISPLAYS
UCD_t = TOTAL NUMBER OF UNIQUE CONTROLS DISPLAYS
FCD_t = TOTAL FS VALUE
FI = FIDELITY INDEX

NOTE 1

THE WORKSHEET CONTINUES UNTIL ALL TASKS WITHIN A DUTY ARE EVALUATED THEN THE LOWER PORTION IS COMPLETED FOR THE DUTY JUST EVALUATED

TOTALS FOR DUTY:

T_t	PCD_t	FCD_t
65	144	162
TR_t	RCD_t	RCD_t
65	50	55
	UCD_t	UCD_t
	5	0
TC	PS	FS
1.00	.87	.98

= TOTAL 2.85 ÷ 3 = FI .95

FORMULAS

$$TC = \frac{T_1 + T_2 + T_n}{TR_t}$$

$$FS = \frac{FCD_1 + FCD_2 + FCD_n}{3\,(RCD_t + UCD_t)}$$

$$PS = \frac{PCD_1 + PCD_2 + PCD_n}{3\,(RCD_t + UCD_t)}$$

Figure 3. Fidelity Worksheet

Initially used as an internal tool, the FV model becomes a paper verification of fidelity definition at the Preliminary Design Review (PDR) and again at the Critical Design Review (CDR). The baseline data documented at the lowest training level (tasks) can then be evaluated objectively *throughout the development, production, and testing* process. For example, if at PDR, a fidelity discrepancy is revealed in design strategy relative to a specific training task, it can easily be reviewed again at CDR and ultimately be evaluated as a separate entity during system testing.

VERIFICATION OF FIDELITY

Test plans and procedures were developed to verify the physical and functional requirements of the simulation work stations. The identification of fidelity requirements between the operational equipment and the training system will have been well defined by this point, and the individual work stations will be ready for system level testing.

Physical verification of the work stations has been an ongoing process throughout the design and layout of hardware components. This verification included such considerations as size, location, and color of controls; readability of displays; and accessibility of components that would require service or maintenance. In addition, safety was also evaluated during physical verification to identify, and control, potential hazards to personnel and equipment inherent in system hardware.

Functional verification, at least on paper, has also been an ongoing consideration during the prior design and development process. Hardware/software interactions and man-machine interface, as documented in the Tasks Listings Report, have been *constantly satisfied up to this point.*

Verification of fidelity requirements will be accomplished primarily through the application of inspection and demonstration procedures, although analysis and testing may also be justified at some later point in the process.

By definition, inspection is the verification that a specification requirement has been met by visual examination of the item, review of descriptive documents, and comparison to a deliverable product of specified standard. In reality, the inspection of each student work station will confirm that all required levels of physical fidelity are present to ensure the direct transfer of each training objective into the work world. In other words, 100-percent physical fidelity will be represented in each simulation work station as determined by the training tasks.

Functional fidelity, on the other hand, is verified by exercising hardware and software under simulated operational conditions for visual confirmation that fidelity requirements are met. It will be demonstrated that system-generated cues will elicit structured or free play inputs and, in turn, the system will react realistically to the students' activities as defined by the previously identified training requirements.

Acceptance or rejection criteria is determined as a GO/NO GO or PASS/FAIL evaluation. Acceptance is defined as satisfying 100 percent of the fidelity requirements identified in each learning objective, whereas rejection is defined as anything less than 100-percent achievement.

A simulation work station will be considered acceptable only after each duty is acceptable, then only if all tasks within that duty have met the *fidelity requirements specified for training*. In the event that a task fails to satisfy its defined fidelity requirements, that task is rejected and the duty (and consequently, the work station) is unacceptable until the level of fidelity required to teach that task is corrected and the task is accepted. With this approach, each simulation work station will then be 100 percent responsive to the required fidelity level necessary to teach operator, maintenance, and analyst personnel to perform their jobs when they report to their future duty assignments.

CONCLUSIONS

Simulator fidelity, as a concern, seems to occur completely in an ex post facto environment. For example, the normal sequence of events is to build the trainer, train the students, send them to the field, then conduct a study to determine trainer effectiveness. AAI submits that this is too late. Trainer effectiveness must be a primary concern at the outset *and must be controlled throughout the* entire design and production process. This can only be done if system design parameters are viewed simultaneously with the identification of training tasks. AAI's fidelity verification (FV) model is one such approach. AAI accepts the fact that the FV model is in its infancy and requires much more data, but holds fast to the idea that the FV approach, or some other model, is critical if the job analysis process is to have its full impact on the emerging training system.

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ABOUT THE AUTHOR

Dr. Bruce is a Senior Engineering Psychologist in the Logistics Division of AAI Corporation. He holds an Ed.D. in Higher Education and has 15 years experience in the design and development of instructional training systems. Since joining AAI in 1984, he has been the ISD Manager for various Government contracts leading to the design of full fidelity SIGINT/EW training devices.